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Making secondary education relevant for all: reflections on science education in an expanding sub-sector

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Abstract

This think piece focuses on relevance in secondary science education to propose a research agenda for contexts in sub-Saharan Africa where enrolments are expanding from a low base. The notion of sustainable work is used to consider what kind of science education is relevant for students, who will continue to become science specialists and those, who will apply their science knowledge in non-specialist paid and unpaid roles. Drawing on insights from the literature on science and indigenous knowledge, on education for sustainable development and sociolinguistic analysis of science classrooms, it is argued that making connections between informal and formal knowledge is essentially the work of secondary education. Understanding secondary education in these terms does highlight its vital contribution to addressing sustainable development, which at its heart recognises the interconnectedness of human and natural systems.

Introduction

The Education Sustainable Development Goal (SDG 4) extends the cycle of basic education, which should be free and compulsory, to include lower secondary as well as primary education. In much of sub-Saharan Africa, lower secondary is very far from being available for all. This think piece is addressed to the problem of designing science education to be relevant to all learners in contexts where up to now very few young people have had access to lower secondary education. It aims to set out a research agenda for countries in sub-Saharan Africa, which have over the last fifteen years expanded provision of secondary education from a low base of around 15-30% or less to around 50%¹ or more and continue to expand enrolments. Expansion at the scale and speed it is occurring across these African countries has profound implications for curriculum and pedagogy. A level of education that previously was available to only a small minority of learners, selected on the basis of academic performance, and who expected to continue on to tertiary education, is suddenly expected to accommodate a

¹ This includes Angola, Benin, Cameroon, Guinea, Lesotho, Liberia, Nigeria, Rwanda, Tanzania, Togo.

much greater diversity of learners. Those learners are likely to pursue divergent education and training trajectories after their compulsory education into further education, training, paid or unpaid work.

Previously, I defined as having a socio-economic and socio-cultural dimension (Barrett 2011). Socio-economic relevance is concerned with how education prepares students for sustainable livelihoods and to benefit from globalisation. The sociocultural dimension concerns recognition of students' sociocultural identities, including their language, the histories of their communities, religious and sexual identities. To this the sustainable development agenda adds a third dimension of environmental relevance, how education engages students with their environment and prepares them to contribute towards preserving and enhancing the environment for future generations (Barrett 2015). This article, however takes a different approach. It focuses on instrumental relevance of lower secondary science education through considering how it prepares learners for different forms of sustainable work. SDG 4 goal to 'ensure inclusive and equitable quality education and lifelong learning for all' (United Nations 2015) is regarded as inter-related with other SDGs. Especial attention is given to the eighth SDG (SDG8), which is concerned with inclusive, sustainable growth and decent work for all. The article draws on a categorisation of sustainable work, presented in the 2015 Human Development Report subtitled *Work for Human Development* (UNDP 2015) (henceforth, HDR 2015):

Sustainable work promotes human development while reducing and eliminating negative side effects and unintended consequences. It is critical not only for sustaining the planet, but also for ensuring work for future generations (UNDP 2015: 14)

Sustainable work promotes human development and environmental sustainability through its products or outputs, and also expands the rights, freedoms and capabilities of the worker. In short, sustainable work is understood in this article as work that contributes to sustainable development, which following the United Nations (UN) definition has social, environmental and economic dimensions. HDR 2015 includes waged employment, self-employment and unpaid work, including domestic and care work.

Secondary education is the level of education at which specialisation begins. Lower secondary is defined by the Incheon Declaration (World Education Forum 2015) as part of the basic education cycle that should be free and compulsory for all and upper secondary as post-compulsory. Somewhere between lower secondary or upper primary level, the school curriculum is divided into subject-based disciplines delivered by subject specialist teachers. Secondary education occupies a liminal position between a common general basic education and offering options for specialisation that have implications for future careers and opportunities. For those, who continue with upper secondary specialisation begins in earnest and options are closed down. However, this article is mainly concerned with lower secondary. Lower secondary lays a foundation for the knowledge, skills, values and attitudes that young people need as they enter the world of work and start to contribute as adults to their communities. It does not usually provide the technical skills for an occupation or profession but should prepare learners

to start training or an apprenticeship that leads to a recognised occupation or profession or for the next step of academic specialisation at upper secondary, which may lead to higher education. For lower secondary education to be equitable it should enable students to move into any form of sustainable work (McGrath and Powell 2016). As a minimum, the design of secondary science education curriculum should not close down post-secondary options.

The article starts by outlining a vision for sustainable development as set out in African Union (AU) documents (African Union 2014, African Union 2015, African Union 2016) and the place of secondary school science in achieving this vision. The next section elaborates on four categories of sustainable work - employment/paid work; unpaid work; voluntary work and creative expression in the light of sustainable development priorities for Africa. The contribution of secondary school science in preparing students to engage in each form of work is considered. The third section, refers to literature on scientific literacies and education for sustainable to argue that the knowledge demands associated with the different categories of sustainable work are compatible, not competing. Research priorities for secondary school science education, identified through the article's discussion, are identified in the conclusion.

African Development Visions: the place of secondary science education

Two main rationales have shaped how secondary education is viewed to contribute towards development. The first, is that secondary education contributes to human development, for example through associations with improved productivity for farmers or depressed HIV/AIDS rates. Campaigns for girls' participation in secondary education have promoted this discourse internationally, making the case that secondary education enhances the agency of girls and women, including through protection of early marriage. However, it is the second rationale, secondary education's contribution to human capital for industrialisation that features most prominently in the African Union documents setting out an agenda for sustainable development in Africa (African Union 2014, African Union 2015, African Union 2016) and also in the policy rhetoric of African countries. The human capital rationale is particularly to the fore within justifications for strengthening teaching and learning of science subjects. The African Union (AU) regional policy frameworks put forward a vision for economic diversification through modernization of the agricultural sector, growth of industries that add value to primary commodities produced within those countries and growth of the service sector. This is echoed in national development visions for low or lower middle-income sub-Saharan African countries, which set out an aspiration to achieve middle income status through industrialisation and diversifying the economy. Many of the national Development Vision documents were written in the late 1990s or early noughties. Ideas about the knowledge economy backed by evidence from rates of return analysis reinforced the role of secondary education in developing the cognitive skills for the uptake of new technologies, in agriculture, in industry but most especially through benefiting from the rapid development and geographic penetration of information technologies (Chen and Dahlman 2006, Roberston et al. 2007). Value added manufacturing and service industries depend on mathematical and scientific knowledge, advanced levels of proficiency in literacy, cognitive skills (e.g. abstract

thinking, problem-solving, e-literacy) and non-cognitive skills (e.g. self-regulation, organization and planning skills) that are developed through secondary education (Lewin 2008).

The SDGs herald a realignment in how development is conceptualised. In essence, the sustainable development agenda acknowledges the interlocking relationship between human and natural systems (Stiglitz et al. 2009, Sachs 2015). Notions of sustainable development are founded on a recognition that human wellbeing and economic growth depend upon and consume finite natural resources. Sustaining development therefore depends on sustaining and replenishing natural resources, or at least, as HDR puts it, 'reducing or eliminating' negative environmental impact. More radical understandings also draw attention to the intersections between social justice and environmental justice (Elliott 2013, Klein 2014). They highlight how the system of global capitalism has allowed exploitation of natural resource on a massive scale, causing huge environmental damage and threatening the livelihoods and wellbeing of local populations. At the same time the power of local actors are curtailed, for example by terms of international trade agreements, undermining the power of local populations to protect their environment.

African leaders have responded to the SDG agenda by setting out regional priorities within the *Common Africa Position (CAP) on the post-2015 development agenda* (African Union, 2014) and then later, *Agenda 2063* (AU, 2015). Both documents emphasise structural transformation for inclusive economic development through modernisation of agriculture for food self-sufficiency, improved nutrition; industrialisation that adds value to primary commodities and diversifies the economy; developing the service sector and infrastructure development. Commitment to environmental sustainability focuses on improving natural resource management, access to safe water, mitigating and responding to climate change, environmental degradation and natural disasters. CAP also includes a commitment to effectively managing conflict and preventing armed conflict. Agenda 2063 reinforces this vision for development but places a greater emphasis on peaceful societies and good governance. It highlights the opportunity presented by the availability of renewable energy sources for environmentally sustainable development through global forums. Most strikingly, however, Agenda 2063 leads with a coherent vision for a continent united through mobility of people and free trade made possible through an extensive communications structure and harmonization of education qualifications, particularly at the tertiary level. It puts forward a confident projection of Africa as a major and unified political voice, which can demand its partners join in 'sustainable management of the global commons'² (African Union 2014: 17). There is little consideration within Agenda 2063 of the tensions between ambitions for economic growth based on capitalist models of consumerism and the demands of environmental sustainability (highlighted, amongst others, by Rist 2008, Klein 2014),

² The global commons includes the planet's natural environment, cross-border communicable diseases, multilateral trade and international financial systems, and global knowledge for development.

although the capacity and potential for industrialisation based on renewable energy is mentioned.

Agenda 2063 sets out the following action concerned with education:

Catalyse education and skills revolution and actively promote science, technology, research and innovation, to build knowledge, human capital, capabilities and skills to drive innovations for the African century ... (African Union 2015: 14)

Education is recognised to contribute to the development of human capital for realising this vision. Universities can drive science and technology research and innovation, whilst the wider education sector can contribute towards the creation of a 'scientific culture' within a 'knowledge society', including through building on indigenous knowledge. The *Continental Education Strategy for Africa 2016-2025* (CESA) (African Union 2016) expands on the role of education. It suggests four ways in which secondary education may contribute to developing STEM capabilities for the Agenda 2063 vision of development:

1. Relevant and inclusive mathematics and science curricula that build on indigenous knowledge
2. Offering Technical and Vocational Education and Training (TVET) opportunities
3. Expanding linkages with the world of work
4. Extra-curricular activities

At the national level, policy rhetoric justifying expansion of secondary education is aligned with the first of the seven Agenda 2063 aspirations, that of a diversified and industrialised economy. Indeed, this has been a consistent theme of regional policies and plans over the last 30 years (Kinyanjui and Khoudari 2013). Hence, mass secondary education has been seen as necessary for developing human capital for modernizing and diversifying agricultural production, for growing industries that add value to primary commodities produced by agriculture or resource extraction and for growing and strengthening the service sector. Specifically, Mathematics and Science subjects are frequently promoted as important for industrialisation and ICT as important for entrepreneurship. For example, in Rwanda, Entrepreneurship and ICT are established as compulsory subjects at the secondary level, in support of its 2020 development vision to become a communications and service hub within Africa (Hayman 2005). The Malawi 2020 Vision has a section concerned with improving science and technology education, training and culture. Last year, the Minister for Education in Tanzania announced that science subjects would be compulsory throughout the four-year lower secondary cycle (Ngwega 2016). A new curriculum in Zambia is intended to strengthen science and mathematics teaching and expand opportunities for engaging in technology and practical subjects (Curriculum Development Centre 2013). Zambia has also introduced a fast track teacher education programme focused on Industrial Arts, Science and Mathematics. Senegal has announced plans to invest heavily in a new science teacher training programme as part of a strategy to address strengthen and extend teaching of

science and technology subjects within secondary education.

Investment in secondary science education is driven by expectations that it will contribute to scientific and technological innovation that can drive development from within the African continent and prepare society to be able to take up and benefit from innovation. Clearly there is a need for research that charts the pathways through which secondary science education delivers on this promise. The next section, aims to suggest a research agenda for such a project through considering the different forms of sustainable work which secondary school graduates may enter either directly, or following post-compulsory education.

Sustainable work: an alternative vision for secondary science education

McGrath and Powell (2016) call for a radical approach to skills for sustainability that goes beyond an instrumentalist concern with earnings and employment to embrace broader objectives of contribution to human development. They argue that such an approach is consistent with ‘some powerful pointers’ within the UN’s sustainable development agenda, whilst also acknowledging the agenda is hemmed in by ‘inevitable compromises’ (*Ibid.*: 16). A commitment to human development and a theory of sustainable work, they argue, must be central to such an approach. Given the hybrid nature of secondary education with respect to a general education and specialisation, the same ideas are pertinent to rethinking the contribution of science learning in secondary education to sustainable development. The 2015 Human Development Report sets out a framework for a broad notion of sustainable work, which is not just about contribution to the production of goods and services but is synergistic with human development. Sustainable work embraces activities that ‘enhanc[e] human rights, freedoms, capabilities and opportunities and by enabling people to lead long, healthy and creative lives’, ‘strengthens society’ and is ‘environmentally friendly’ (UNDP 2015: 29). To illustrate this, four types of work are identified - employment or self-employment that is paid; unpaid work, which HDR 2015 equates with care work but which can also include subsistence activities; voluntary work and creative expression. A person may engage in different types of work at different stages of life. Indeed, paid or unpaid work may become unsustainable simply because it is undertaken by people at an inappropriate stage of life, for example children and teenagers undertaking excessive care work, which interrupts their education. Extending the compulsory cycle of basic education to include lower secondary education should protect children from unsustainable work. Beyond this however, secondary education is tasked with expanding young people’s opportunities to engage with and choose between different types of sustainable work.

Table 1 takes HDR2015’s categories of sustainable work as a starting point for suggesting science curricular goals that develop capabilities for each. The purpose is to explore how lower secondary education can lay a foundation of scientific knowledge and skills that is required to start down the path towards any point on the full range of sustainable work. The suggested curricular goals are not intended to be comprehensive. They serve as a starting point for highlighting the contribution that three sets of education literature and research can contribute to understanding relevance and equity within secondary science education in the SDG era. Three sets of literature are drawn upon in particular:

education for sustainable development (e.g. Matthewman and Morgan 2013, Wals et al. 2014); scientific literacy (Aikenhead 2007, Roberts 2007); and literature on science education in Africa (e.g. Semali and Mehta 2012). By using the sustainable work framework to ask questions of relevance in secondary education, it is not assumed that secondary education should be tasked with preparing students with all the skills and knowledge they need to enter directly into the world of work. Rather secondary education is regarded as a common foundation or launch pad from which young people may enter vocational education and training or higher education. Nevertheless, it should be recognised that lower secondary is the highest level to which many young people will formally study science subjects. Neither, by focusing on preparation for sustainable work, is it intended to deny the intrinsic benefits of education and studying science within secondary school may be enjoyable and worthwhile in itself. The following section considers the curricular goals pertinent to each row in the table.

Table 1: Science education for sustainable work

Categories of sustainable work (HDR2015)	Sub-categories or examples (HDR2015)	Implications for secondary science curricular goals (author's suggestion)
Jobs/employment	Wage employment STEM specialisms include STEM R&D; Health, science education, engineering, technology-based occupations	<i>(for STEM employment)</i> General science knowledge Methods and skills of scientific inquiry Curiosity to pursue scientific specialisation Skills for intra- and interdisciplinary collaboration Understanding complex systems Communication skills
	Self-employment STEM specialisms include technology based enterprises	<i>(for STEM self-employment)</i> Above Plus: Creativity Problem-solving
Unpaid work	Examples: Water/fuel collection, tending to sick, cooking, caring for children, cleaning, gardening, rearing domestic livestock.	Everyday science e.g. science for health and hygiene Understanding of local eco-system Ability to source, interpret and judge the reliability of scientific information
Voluntary work	Informal	Communicate science knowledge to diverse audiences Apply science knowledge to local and global social and environmental issues Sense of social responsibility
	Organisational	

Creative Expression	Examples: Writing, animation, sculpture, dance, poetry, design, drama photography, music painting	Use technology to create outputs Communicate science knowledge to diverse audiences 'Translate' science knowledge between media Skills for interdisciplinary collaboration
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Secondary science as preparation for jobs/employment in STEM

STEM-related Jobs/employment is clearly a very wide category that includes work requiring a high degree of specialisation in skills and knowledge to those that are unskilled. I start by considering what kind of science education is relevant for secondary school students, who go on to study science, technology, engineering or mathematics (STEM) subjects at higher education and from there into STEM jobs that require a high degree of specialisation. This includes work in research and design (R&D); manufacturing and productivity, including in agriculture, engineering and mining; training, education and communication; environmental protection and social care and development. For science and technology professionals, upper secondary is the first step in an extended educational career that involves several years of higher education to acquire advanced highly specialised skills and knowledge. This section considers the ways in which secondary science education lays a foundation for some kinds of advanced STEM -related employment. Areas of sustainable work involving STEM specialism discussed are: STEM R&D; health, science education and engineering and technology based occupations, which includes employment and self-employment in technology based enterprises.

STEM R&D

Research and innovation for sustainable development, particularly in science and technology, is prominent within AU's Agenda 2063. In this area, though, there is ground to catch up. A recent study by The World Bank and Elsevier (2014) found that the quantity and quality of published STEM research originating from within sub-Saharan Africa is much lower than for any other world region. The research that is published tends to depend on international collaborations and be heavily skewed towards agriculture and health sciences (World Bank and Elsevier 2014). Shortage and high mobility of researchers in STEM subjects, particularly physical sciences, is one reason given for this. Whilst Agenda 2063 places emphasis on agricultural research for food security it also highlights research for manufacturing, natural resource exploitation, development of bio-energy and communications infrastructure. African visions for a diversified industrialised economy that place a heavy emphasis on

STEM R&D can lead to calls for a discipline-based, theory-oriented secondary school science curriculum. This is seen in the current policy initiatives to promote science education, as in the examples of Tanzania and Senegal referred to above. It is also seen

in the various JICA-sponsored in-service professional development programmes targeted at mathematics and science teachers, which privilege teachers of the three traditional natural science disciplines. This approach aligns with the argument, put forward by curriculum theorist Michael Young, that specialist knowledge is powerful knowledge because disciplines establish criteria for judging truth claims of universal theories (Young 2009). Hence, Young argues, an equitable secondary education offers all learners, irrespective of their background, discipline-based subject teaching.

Equity of access to secondary science education is a critical issue for many African countries, where the supply of talented, well prepared upper secondary school graduates is a major bottleneck for recruiting into STEM R&D and science-based professions. STEM R&D depends on recruiting the most talented from a large pool of applicants but in many parts of Sub-Saharan Africa, completing upper secondary is strongly dependent on socio-economic wealth. For example, in Malawi only 8% of the rural population and 2% of the poorest quintile complete upper secondary education, compared to 37% of the urban population and 39% of the richest quintile (data from 2013 from WIDE database). In Tanzania, only 1% of the poorest quintile complete secondary compared to 22% of the richest quintile. Improving equity of access to secondary education of an adequate quality is an imperative for achieving ambitions for STEM R&D. Research published by the World Bank has highlighted the now list of challenges, to improving quality, familiar to any education and development research (Ottevanger et al. 2007, Bethell 2016). In brief, these include attracting, preparing and retaining qualified teachers, who are secure in their subject knowledge; supporting professional development and motivating teachers; equipping schools with science laboratories, suitable ICT and instructional materials. Significantly for this paper, the list includes revising overloaded and imbalanced curricula.

When STEM R&D is, justifiably, a major development priority, there is a temptation to develop over-ambitious curricula targeted at preparing academic high performers for the next educational level. This, however, is counterproductive. Curricula that are poorly adapted to the age and educational level of learners and that take no account of the realities of learning environments and the expertise of teachers raise barriers for talented students from disadvantaged backgrounds, or in other words, the majority. CESA's (African Union 2016) aspiration to strengthen mathematics and science curricula including through promoting 'indigenous scientific knowledge and culture' indicates a positive direction in this respect.

An inclusive curriculum introduces formal scientific concepts, theories and methods of inquiry using the material, linguistic and cognitive resources available to students within diverse African contexts (Gray 1999, Engida 2012) may do more to expand and improve talent available to STEM R&D in Africa than a curriculum that revolves mainly around preparation for the next educational level. This requires curricula designed within country that builds on but is never limited by the knowledge students bring to class and

applies formal scientific knowledge to problems of sustainable development within students' contexts (Semali & Mehta, 2012).

Health, science education and engineering

Human development requires a professional workforce that has completed both a secondary and tertiary education. HDR2015 conservatively estimates that achievement of the SDG education and health targets for the sub-Saharan African region require an additional 5.7 million teachers (2.1 million for primary and 3.6 million for secondary) and 3.8 million health workers respectively, not taking into account pre-school teachers, trainers and managers. As with STEM R&D, secondary school graduates aiming to work in social professions require a grounding in science and mathematics. However, for education and patient facing roles within health provision, interpersonal skills and communication skills are also paramount, including the ability to communicate scientific knowledge effectively to people, who may not have completed secondary school and may not be fluent in a national language. Indeed, the principle that sustainable work contributes to human development implies that all professionals, including STEM-based professionals such as engineers, have a responsibility towards human development and social justice, most especially in contexts where only a minority participate in tertiary education (Case 2007, McLean and Walker 2012). Consideration of these destinations highlights the need for a curriculum that develops written and verbal communication skills, makes connections with local knowledge systems and explicitly addresses ethical and social issues that relate to science. In short, a critical education that is concerned with the cognitive, creative, affective and moral development of learners.

Technology-based occupations

Currently, in many low income countries, the formal sector cannot absorb all the graduates from formal basic education. In sub-Saharan African countries, 66% of non-agricultural work in sub-Saharan Africa is informal (UNDP, 2015: 63). Secondary education, therefore, should lay the foundational skills for self-employment and entrepreneurship. This includes business skills, problem solving and creativity but also confidence and leadership skills. Poor language skills of students and insecure subject knowledge of teachers contribute to superficial learning, where students learn to reproduce memorised text, rather than the production of meaningful written or spoken outputs by the learner (Barrett and Bainton 2016). Contextually relevant, linguistically accessible learning resources that relate scientific knowledge examples and problems within their own environment can support the development of problem-solving skills. Researchers concerned with science education research in Africa have over several decades called for more use of problem-based approaches to science education (e.g. Knamiller 1981, Semali and Mehta 2012).

Artisan or trade occupations, e.g. building and construction, motor mechanics, electricians, textiles, also require STEM knowledge, with more emphasis on technology. CESA, as we have seen above, highlights inclusion of technical and vocational education and training opportunities at the secondary level and linkages to work the place. In several African countries, technical and/or vocational secondary schools provide young

people, who, usually on the basis of examinations scores, are considered likely to move into such occupations. Several countries already have such vocational streams, including Ghana, Senegal and Côte d'Ivoire, that have been established for some time and Zambia is trialling a new vocational curriculum. DeJaeghere (2013) notes the growing influence of entrepreneurship programmes in schools serving disadvantaged young people, often supported by NGOs or social enterprises. Universalisation of secondary education raises key questions around the extent to which applied technology subjects (e.g. technical drawing, design and technology, agriculture, domestic science) should be included in secondary education. Should they be offered as options within general schools or should students be selected into academic and vocational schools? Should vocational and academic streams start at lower or upper secondary? Which subjects should be offered? What opportunities are there for secondary schools to collaborate with local providers of vocational education and training that have a track record of training primary school leavers into locally-available jobs? These are not questions with a single answer but need to be addressed through situated analysis of existing provision of post-primary education and training, complementarity with tertiary provision, local employment opportunities, and implications of diversified curricula for social inequalities and political feasibilities.

Rapid urbanisation and the increasing penetration of computer, broadband and mobile networks is changing the nature of work and the kind of technological expertise that is in demand. In response, most African education systems have introduced ICT as a compulsory subject at lower secondary, despite very uneven distribution of hardware and software for delivery of the subject. Employment opportunities are often in local small and medium enterprises and involve use of ICT to create outputs (e.g. graphic design, editing video or music). Hence, curricula and pedagogy at secondary education should be targeted at developing capabilities to use ICT creatively (Rubagiza et al. 2011). This implies that effective delivery of ICT in secondary schools requires higher grade equipment than is currently available in the majority of secondary schools.

Unpaid work and non-specialist jobs/employment: everyday STEM knowledge

Lower secondary education should prepare learners with a foundational level of STEM knowledge that enhances everyday lives in the domestic and work spheres. The areas of unpaid work highlighted in HDR2015 include domestic labour, care work, small scale or subsistence farming. At the primary level, science education may have a focus on knowledge needs for health and hygiene, whereas secondary education tends to have a more theoretical orientation but may include some 'lifeskills' content. For example, as well as theoretical content on cells and categories of living things, the lower secondary Biology syllabus in mainland Tanzania includes topics on disease and infection that focuses only those that are endemic to Tanzania. The influence of the international SDG agenda may lead to greater emphasis on environmental science and the impact of human activities on the environment within the curriculum for Biology. Some STEM knowledge that is relevant for unpaid work is currently delivered through more vocationally oriented lower secondary subjects such as agriculture or domestic science, that are not compulsory and not offered by all schools. This may well be what Agenda 2063 means by 'scientific culture' and a knowledge society.

Kinyanjui and Khoudari (2013) in their synthesis of an Association for the Development of Education in Africa (ADEA) theme on science, technology and innovation argue that indigenous knowledge systems together with school systems form the foundations for lifelong STEM learning that allows for adaptation and uptake of new technologies and responses to sustainability challenges. Hence, school systems need to build on indigenous knowledge and teachers need to be prepared for this. Allowing use of local languages in education in classroom makes it easier to engage with and build on the dynamic STEM knowledge that students bring from their communities. As secondary education is expanding, many older teenagers enrolled in secondary schools are also economically active, sometimes in occupations that depend on local environmental knowledge, such as fishing, small-holder farming or cattle-herding. Building on the knowledge students bring from these activities may make the secondary school curriculum more relevant. It is certainly consistent with longstanding socio-cultural and constructivist theories of learning that emphasise building on prior knowledge and learning (Leach and Scott 2003). Indigenous and informal knowledge is encoded in community languages. Rigidly monolingual language policies can minimise the opportunity for engaging with learners' common sense ideas about science (Gray 1999, Barrett and Bainton 2016).

Subjects viewed as vocational, such as Agriculture and Domestic Science, can have substantial theoretical science knowledge organised and presented in a way that is more immediately meaningful and obviously of practical value for older teenagers, who are already engaged in work around the home or in their family farms. Ottevanger et al. (2007), in a study of Mathematics, Science and ICT education in 10 sub-Saharan African countries, observed a move towards more integrated science curricula at the lower secondary education. This can make natural sciences more accessible to more learners at this level and opens up curriculum space for exploring the interconnections between natural systems (e.g. the impact of chemical pollution on living organisms). Ottevanger et al. (2007: 14) highlight the example of Namibia's Life Science curriculum, which brings combines 'biology (emphasis on human physiology), agriculture (emphasis on animal husbandry) and, environmental education.'

Thinking about the STEM knowledge needs of people, who are not STEM professionals, highlights the need for STEM teaching at lower secondary level to be relevant, attractive and accessible to diverse learners with a wide range of abilities and career aspirations. As lower secondary becomes part of the universal and compulsory basic education cycle in reality and not just policy rhetoric, this will be increasingly important.

Voluntary work and creative expression

Within voluntary work, sharing knowledge, awareness raising or campaigning and lobbying on social issues may be key activities. Understanding of social issues can hinge on scientific knowledge (e.g. for issues related to health and wellbeing, the environment or land use). Voluntary work may demand skills in communicating STEM knowledge to diverse audiences within multilingual societies. The teaching and learning of science cannot be separated from communication skills. Indeed, within sociocultural learning theory, science learning is understood as learning *to* talk rather than learning *from* talk (Daniels 2001: 72). The work of sociolinguists, shows that it is not enough to

learn communication skills in parallel to science but there are subject specific language skills developed through learning science (Coyle 2007). STEM education cannot be compartmentalised as separate from or independent of language and literacy. Learning to read, write and talk about science is intrinsic to learning science (Polias 2016).

Like, the social professions that require STEM knowledge, engagement in voluntary work is often underpinned by social or morally-based motivation. So, consideration of this kind of work also highlights the benefits of a secondary science curriculum that allows for exploration of the intersection between human and natural systems and develops critical thinking that brings together cognitive knowledge, moral reasoning, creativity and a capacity for compassion (Martins 2007).

Creative expression, as a category of work, brings together concerns for communicating scientific knowledge and creative entrepreneurship that have already been discussed. STEM knowledge can enable creative expression through some media or enable commercial exploitation (e.g. ICT skills for audio-visual editing, chemistry for creating dyes). Therefore, a quality secondary STEM education, in which learners create and not just reproduce written and oral outputs and learn through a language they understand whilst developing their language skills further can lay down foundational skills for work in the domain of creative expression as well as entrepreneurship, self-employment and voluntary work.

The concept of STEAM, Science Technology, Engineering, Arts and Mathematics, is pertinent here. The concept originated in the United States with a dual rationale for develop creative and problem solving skills amongst STEM professionals that are demanded by industry and making science education more engaging so that more young people are recruited in STEM subjects (Cultural Learning Alliance 2014). At its most generic, a 'STEAM' discourse is used to champion the Creative Arts as part of a balanced education, particularly at times and in contexts where Arts subjects are relatively neglected in terms of funding or status (Welch 2012). Small scale initiatives, however, have developed STEAM curricula and pedagogies at various levels of education from primary up to higher education (Madden et al. 2013, Oh et al. 2013, Henriksen 2014). These vary widely in design but may involve Arts teachers in delivering part of the science curriculum using pedagogies from visual or performing arts education; multidisciplinary teaching with teachers collaborating to design integrated curricular components that usually engage students in problem solving using knowledge from across STEM and arts subjects; and/or an exploration of how science, technology and mathematics are applied in the creative industries. There is potential to apply the STEAM concept to African contexts to transform negative perceptions many students have of STEM disciplines (Bethell, 2016) and strengthen the place for creativity and problem-solving in national curricula (Ottevanger et al. 2007; Semali and Mehta, 2012). Indeed, the intention behind STEAM seems to be in step with the vision for innovation-driven sustainable development set out in *Agenda 2063*.

Scientific literacy and education for sustainable development: the work of secondary education

The competing priorities for secondary school science highlighted by application of the HDR 2015 sustainable work framework have long been the subject of debate and scholarship by researchers focused on science education. Whilst scientific literacy has been described as an 'ill-defined and diffuse' term (Dillon 2009: 202), it has been in use since the 1950s. Roberts (2007: 9) brought some clarity to the term by identifying two visions within the debate on scientific literacy. Vision I looks inward to the discipline of science and is concerned with enabling 'students to approach and think about solutions as a professional scientist would'. Vision II looks beyond the parameters of formal scientific knowledge to develop 'skills sets that enable students to approach and think about situations as a citizen well informed about science' (*Ibid.*). Hence, Vision II addresses the relevance concerns raised by the last two sustainable work categories of voluntary work and creative expression, and also applications to human development and social justice, which are of relevance for STEM-related professions. South Africa has introduced Mathematics Literacy as an alternative to more typical formal Mathematics. Mathematics Literacy focuses on developing mathematical skills that are demanded by to function in society, such as calculating tax returns or planning a road trip using a map.

Aikenhead (2007) suggests that a Vision III should be added to the concept of scientific literacy, which positions what he views as Eurocentric academic science alongside other longstanding systematic ways of knowing the natural world. Specifically, Aikenhead identifies indigenous sciences that have enabled first peoples to survive and thrive in their localities they have occupied for thousands of years and what he terms neo-indigenous sciences which are longstanding ways of knowing developed by non-European mainstream cultures, such as Islamic, Bhutanese and Japanese traditions. Ezeife (2003) however, points out that the science disciplines, and Mathematics in particular, have an international history, which extends well beyond Western traditions. If Vision III is equated with the sociocultural dimension of relevance then this is as much about highlighting African contributions to the so-called Western science as engaging with indigenous knowledge systems. On the basis of a comparison of the curricular goals of contemporary secondary science curricula in Europe, Turkey and South Africa, Dillon (2009) argues for 'scientific literacies'. In addition to Vision I and II, he identifies three types of scientific literacy: practical scientific literacy concerns the application of scientific knowledge to solving practical problems; civic scientific literacy concerns scientific knowledge for informed public debate; and cultural scientific literacy concerns knowledge about science as a social activity and major human achievement.

The sustainable development agenda brings into focus our relationship with the environment. A concern for the environment has been argued to reinforce the place of natural sciences and mathematics in the secondary curriculum and expand their purpose (Wals et al. 2014), as the subjects that are primarily concerned with the natural world. Bangay and Blum (2010) on the other hand, highlight how the uncertainties of rapid technological and environmental change demand the preparation of flexible, creative, critical thinkers. Other education for sustainability theorists draw on systems thinking to understand the multi-various and complex ways that social, economic and

natural systems are interconnected (Wade 2008, Blewitt 2012). This leads to calls for the radical transformation of education, which conflicts with institutional demands placed on secondary education (Sterling 2001). Matthewman and Morgan (2013), writing as secondary teacher educators, pragmatically recognise the endurance of school subject disciplines at the same time as acknowledging that their formation was linked to the emergence of modern industrialised carbon producing societies. They call for secondary school teachers to 'examine how their own 'subject' is dealing with the most important issue of our time - the transition to sustainable futures' and to engage with 'ideas and perspectives from other fields' (*Ibid.*: 99). As has been discussed above, the pathways for the emergence of modern societies in sub-Saharan Africa have led to and continue to lead to the emergence of secondary STEM subjects that are not widespread in Anglo-western countries, such as agriculture and very recently in Zambia, Industrial Arts. Nonetheless, the traditional three science subjects of Physics, Biology and Chemistry also have endurance. Matthewman and Morgan's argument calls for a re-conceptualisation of secondary school teachers as not just subject specialists but engaged lifelong learners engaged in intellectual conversations across disciplines.

Sociolinguistic research has shown how formal scientific knowledge, Young's powerful knowledge, is formulated using language as it is written and not how it is spoken (Halliday 1993, Martin 1993). Constant movement or translation between formal discourse of written language and informal talk is a key characteristic of secondary school classrooms. In other words, informal and formal knowledge are both meaning making resources used in parallel in the secondary school classroom. It is precisely the work of secondary education to introduce students to powerful knowledge of subject disciplines and to connect to, modify and extend common sense knowledge, all of which contributes to the development of scientific literacies. Further, this work is central to the aims of education for sustainable development, because it develops the kind of critical thinking that can draw connections across disciplines to bring scientific knowledge, knowledge of social systems, moral reasoning, creativity and compassion to bear on chronic local and global problems. The discussion of the sustainable work framework shows that scientific literacies and the critical thinking for sustainable development they support are equally valuable for STEM researchers, for professionals, for entrepreneurs, for artisans, for domestic work, voluntary workers and creative expression, in short for all forms of sustainable work.

Conclusion

The sustainable work analysis presented in this article reinforces the position of target 4.1 as an essential part of the SDG architecture and affirms the inclusion of lower secondary within the target. It asks outward looking questions of what is meant by relevance that take us beyond the domain of education to consider the knowledge needs related to all aspects of sustainable development. Four priorities for research on secondary science education follow from the analysis. First, research is needed to develop curriculum design processes that build upon and relate back to the indigenous and informal knowledge of communities, including the knowledge applied in paid and unpaid sustainable work. The development of the iSPACES curriculum framework in Northern Tanzania, informed by theories of culturally responsive pedagogy, is an

example of such a curriculum design initiative (Semali 2013). The second priority arises from the need for STEM professionals and those engaged in STEM related voluntary work and creative expression to be able to communicate scientific knowledge to diverse audiences in Africa. This highlights the need to develop pedagogy and curriculum informed by an understanding of the interdependence between science learning and language learning so that students are supported to develop skills for reading and writing science together with the ability to talk about science in the languages of their community. Third, as secondary education is universalised there is need for renewed efforts to ascertain the technology-based subjects and integrated science subjects that are relevant to local employment opportunities and livelihoods. This includes consideration of the technologies and equipment, including ICTs, that schools will need to support learning skills and knowledge associated with these subjects. The fourth research priority should be inquiry into the forms of teacher professional development that brings teachers together to adapt curriculum to their students' environment, including informal knowledge systems with their environment. This includes engaging teachers as lifelong learners in debate on contemporary sustainable development challenges within and beyond their discipline.

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